Intelligent Mission Management

Chad Frost

Autonomous Robust Avionics (AuRA) Project

NASA Ames Research Center

650-604-1798

Chad.R.Frost@nasa.gov

Contribution to HALE Sector

- **GOAL:**
  - Autonomous Mission Operations (Goal: 100% Autonomy)
- **OBJECTIVE:**
  - Full autonomy during emergencies
- **TECHNICAL CHALLENGE:**
  - Develop real-time flight planning, health monitoring and re-configuration
  - Develop long endurance unaided autonomous operations and navigation
- **APPROACH:**
  - Develop artificial intelligence and integrated vehicle health management, including damage tolerance

Scope of Work

Mission-driven focus:

Earth science and applications

Planetary exploration

Emphasis on:

Mid TRL for sustained operations (terrestrial)

Low TRL for remote operations (next generation planetary)

Integrated systems approach:

Air vehicle

Payload

Ground element (mission team)

Other mission assets (e.g. satellite, land-based, etc… observations)

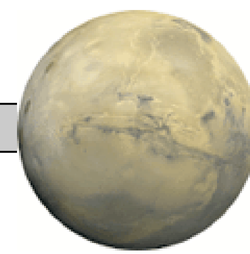
Missions

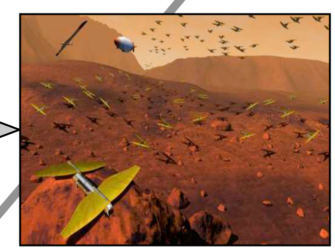
5-year
(En-route operations)

15-year
(100% Autonomy)

Earth Science and Applications (Sensorweb)

Wildfire Research and Applications Partnership
NASA HQ/SMD Applied Sciences Program
PI: Dr. Vince Ambrosia





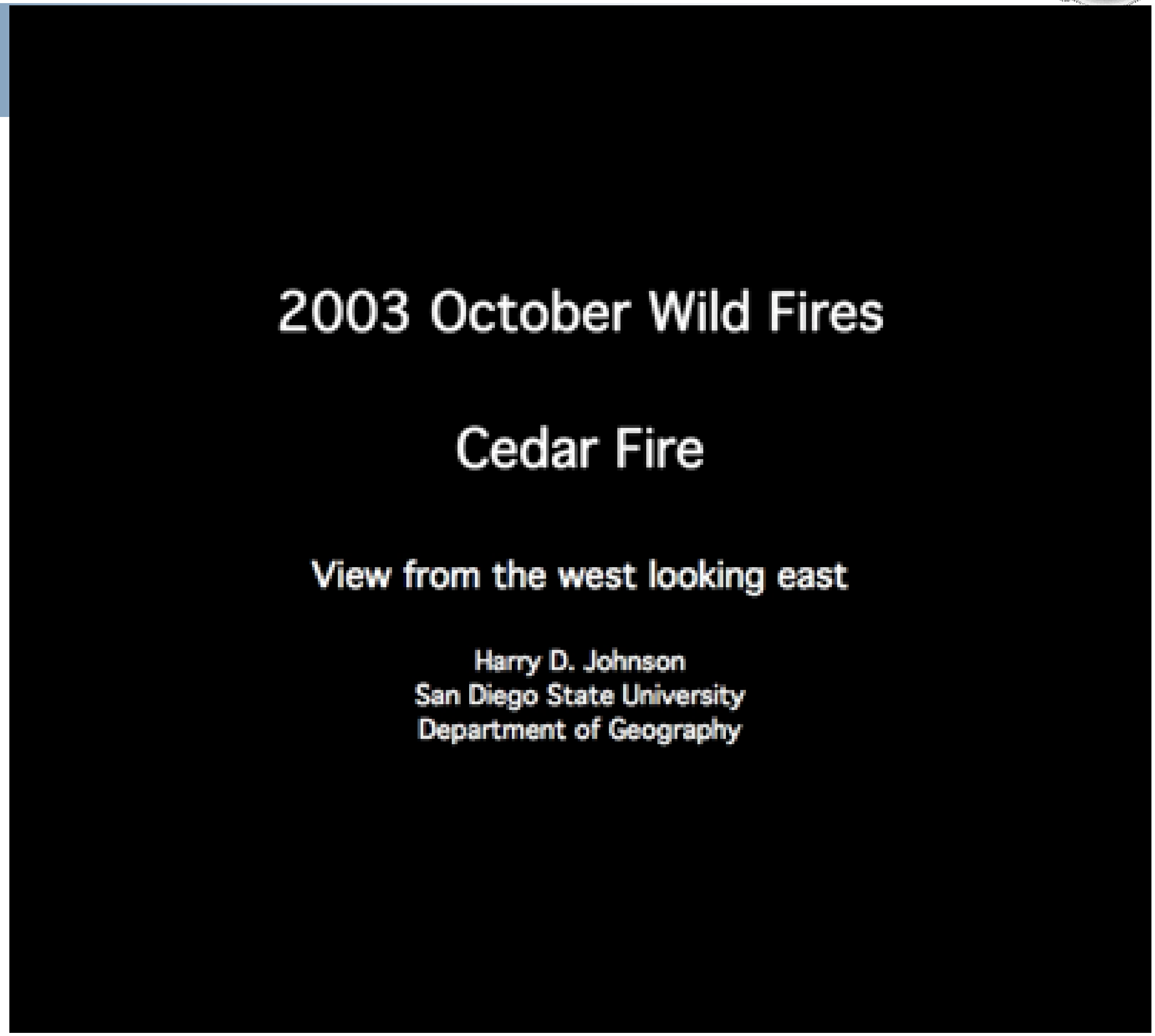
Planetary Exploration (Modular, Scalable, Flexible)

A Plug-and-Play Architecture for Real-Time Intelligent Avionics
NASA HQ/ESMD Advanced Space Technology Program
PI: Dr. Kalmanje KrishnaKumar

Missions

Need for faster turn-around of wildfire mapping motivates Earth Science mission;

Real mission requirements drive technology forward.



Movie clip dramatically illustrates how quickly large fires can grow

http://map.sdsu.edu/fireweb/animations.htm

Key Deliverables

10/06 - Collaborative Decision Environment Demonstration

- Mission-level decision support
- Automated data products
- Sensor planning service

07/07 - Common Outer-loop Architecture Flight Test

- Autonomous reasoning (dynamic replanning)
- Intelligent flight management system
- Tactical maneuvering

04/09 - Remote Mission Operations Field Analogue Test

- Coordinated operations (satellite, base station, rover, UAV's (all classes), etc…)
- Hybrid mode control (conventional/payload-directed/image guided)

Derived from Sector GOTChAs and Mission Requirements

Measuring Mission Success

Mission Score (M) = Benefits − Costs

$$M = \underbrace{\left(\sum_{t=1}^{T} v_t c_t r_t s_t (1-\gamma)^{o(t)} \right)}_{\text{Benefits}} - \underbrace{\left(\sum_{i=1}^{n} (H_i \cdot W_i) + P \cdot (R \cdot C_v + M \cdot C_m) \right)}_{\text{Costs}}$$

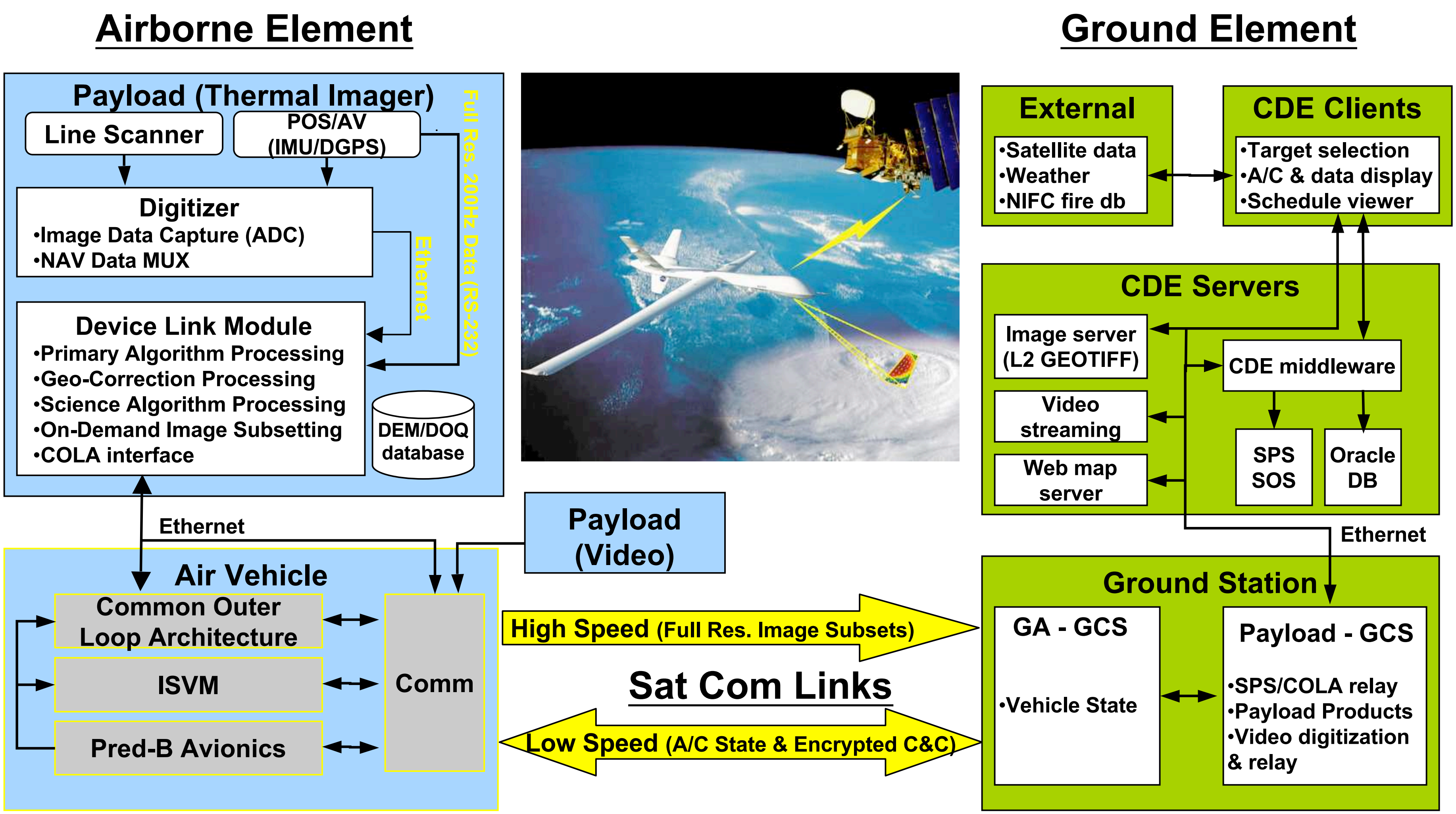
Benefits:

1. Aggregate value of all observations made over mission (ideal v_t=1)
2. Function of target coverage (c_t), resolution (r_t), clarity (s_t), obsolescence of measurement (1-γ), and obsolescence of data product upon delivery ($o(t)$).
3. Challenge is in measuring the aggregate value of returned information.

Costs:

1. Sum of operational personnel costs (100% autonomy implies $H_i \bullet W_i$ = 0)
2. Probability of failure (P) X Cost of failure of the vehicle (C_v) or mission (C_m)

Collaborative Decision Environment Architecture

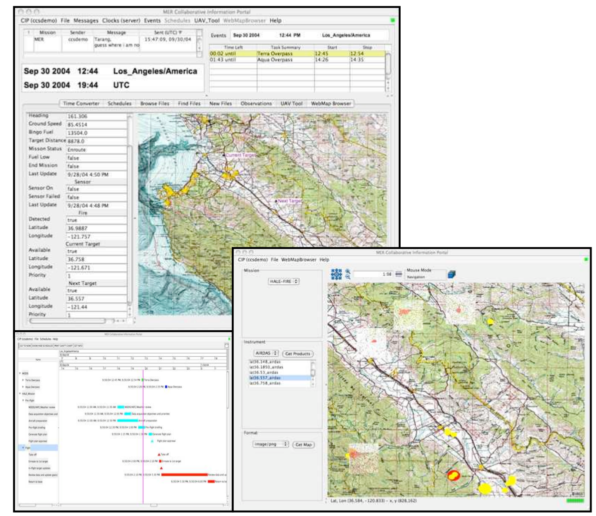


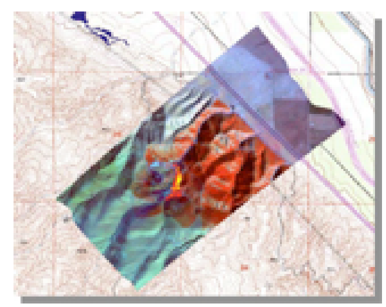
CDE Accomplishments: Simulation Demo

CDE Prototype Demonstrated in Simulation

- Event scheduling, including MODIS overpasses and ground swath
- Live connection to USFS and U. of Maryland for fire data
- Active CDE client/middleware interface to on-board autonomy
- Interactive map, targeting, and a/c status displays

Note: CDE (web-based) client designed for use by geographically dispersed mission/science team and other key stakeholders

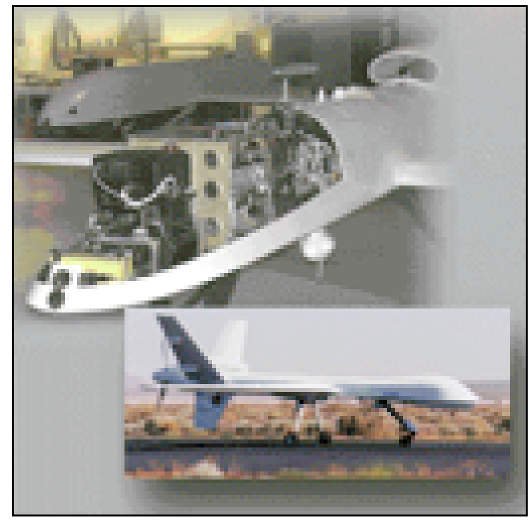




CDE Accomplishments: Sensor Planning Interface

Sensor Planning Service Interfaces Standardized

- Proposal to implement sensor planning service for planning and managing data acquisition from UAV-borne sensing devices approved by:
  - Geospatial Interoperability Office (GIO) at NASA GSFC
  - Open Geo-spatial Consortium (OGC)



- Device link module (DLM) integrated into payload chassis

- Payload-to-DLM software interface implemented as an UDP service

- Payload-to-high speed serial (C and Ku band) interface defined based on space packet protocol for OTH communications

Common Outer-Loop Architecture (COLA)

Key Elements

- Autonomous reasoning (dynamic replanning)
- Intelligent flight management system (iFMS)
- Tactical maneuvering

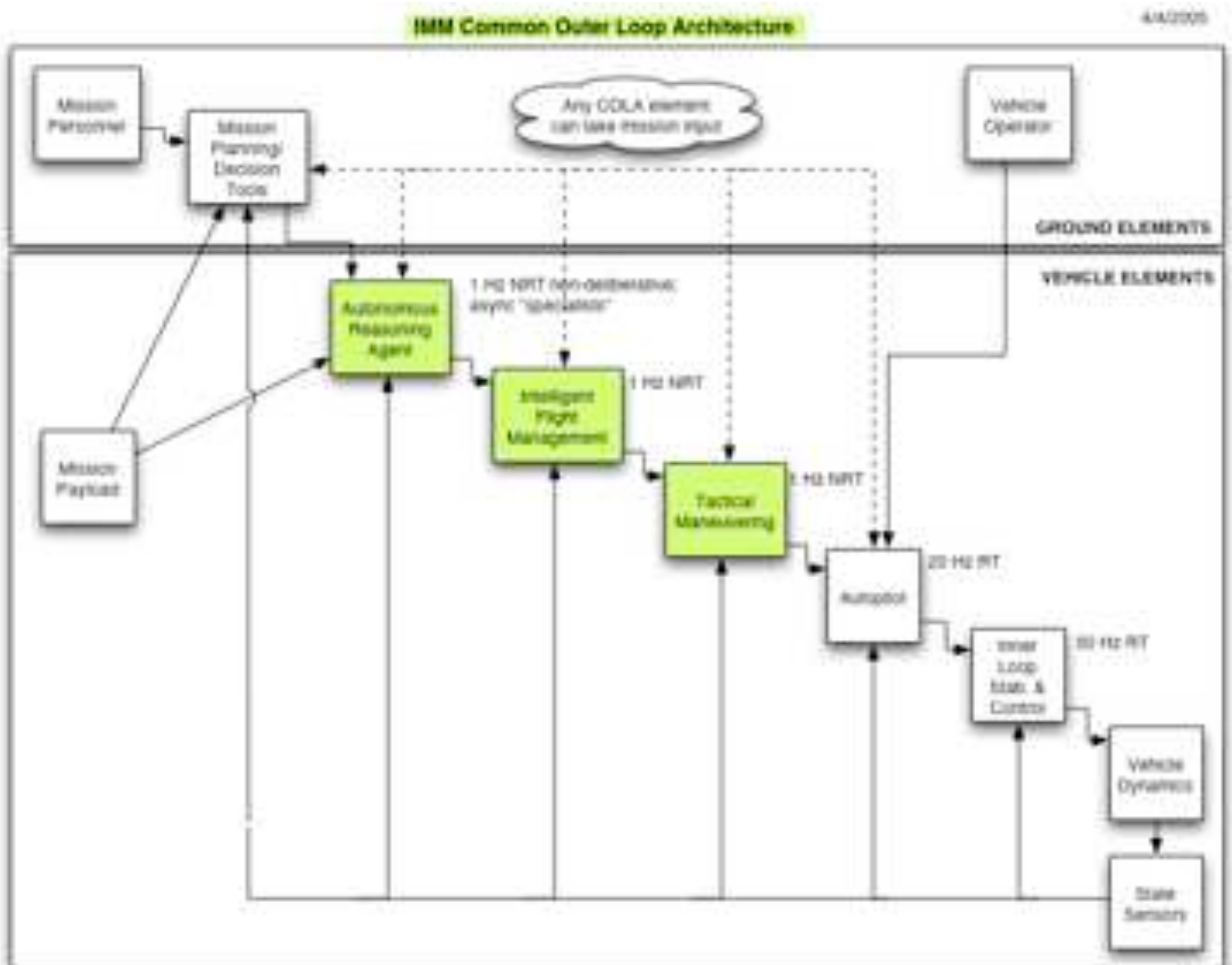
Architecture independent of vehicle class, scale, or mission

- Individual modules may require tailoring to vehicle and mission
- Structure is invariant

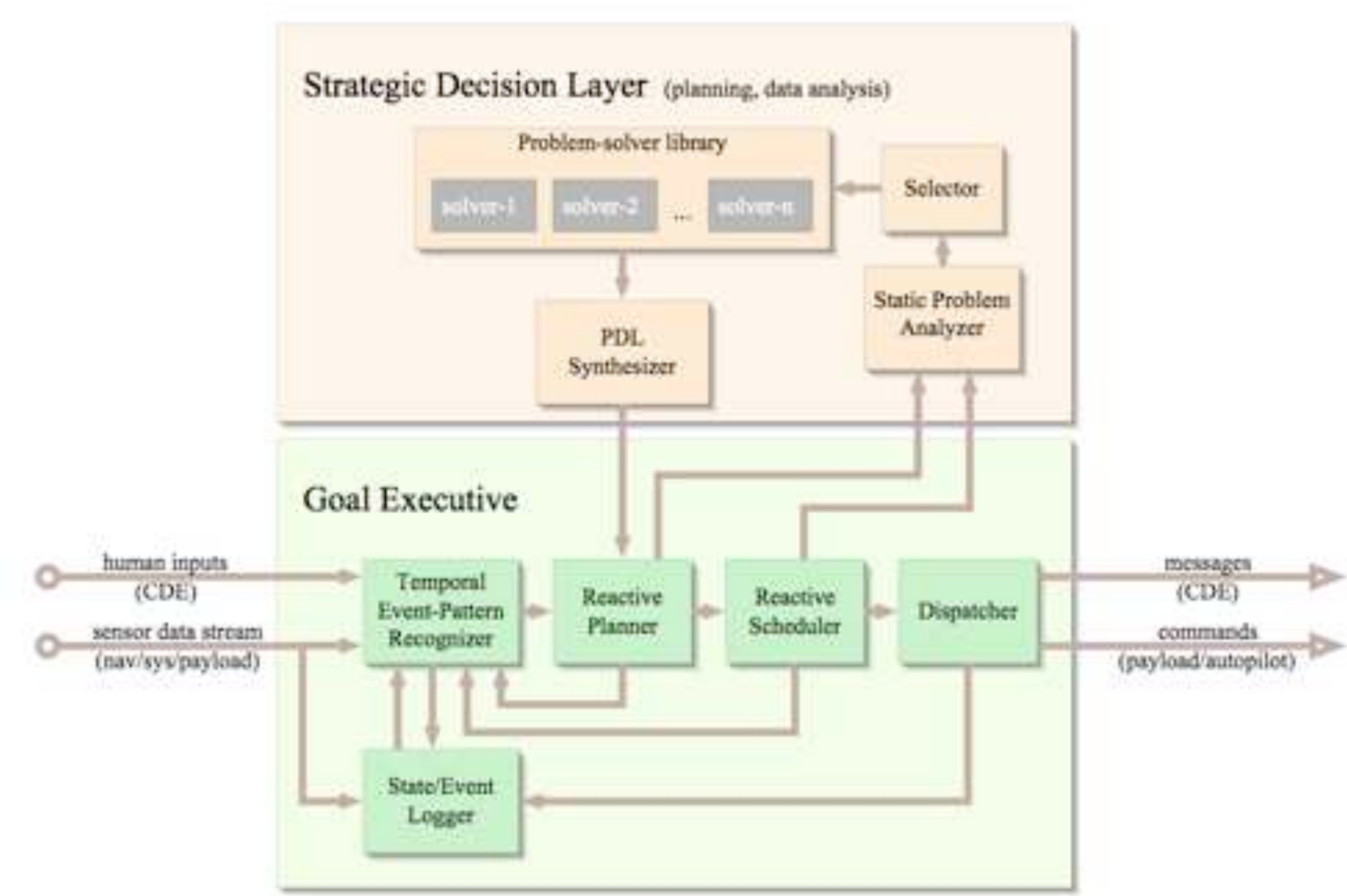
Modules are highly independent

- Results in a system that is Robust and Testable

COLA diagram



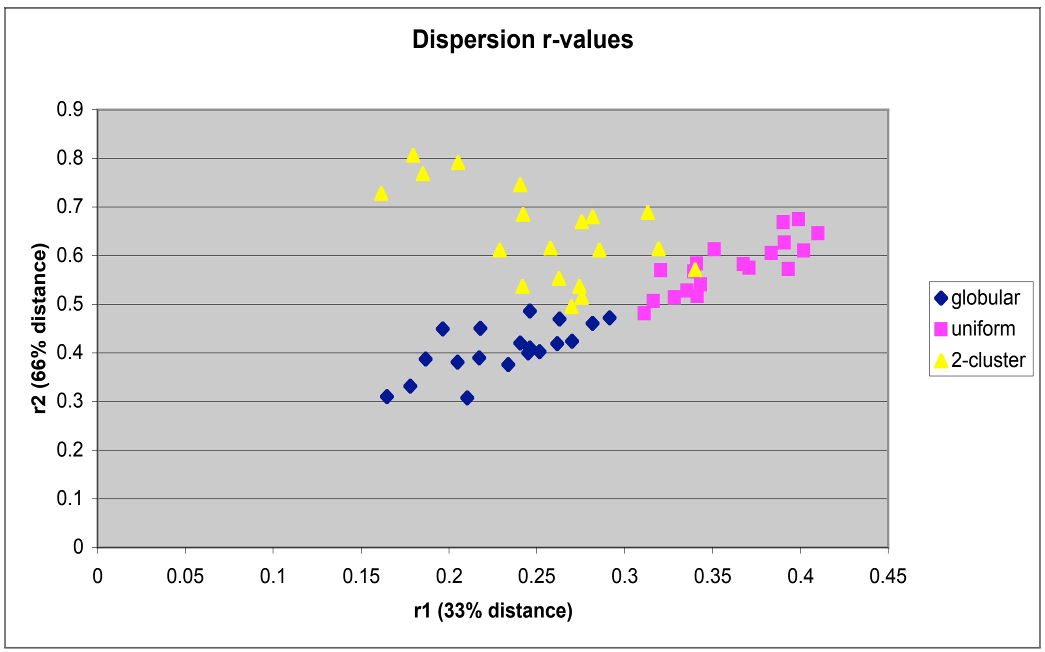
COLA Autonomous Reasoning Agent



COLA Accomplishments: dynamic replanning

Autonomous Reasoning Agent (dynamic replanning)

- Creates plans to achieve mission goals in an uncertain and constrained environment
- Re-plans when goals, conditions or requirements change
- Directs execution of plans by payload, other COLA elements



One project goal is to increase mission success by accumulating new "niche" algorithms rather than by trying to engineer some all-encompassing all-purpose algorithm.

At left: Results of new heuristic for deciding which spatial pattern type most closely matches the current mission.

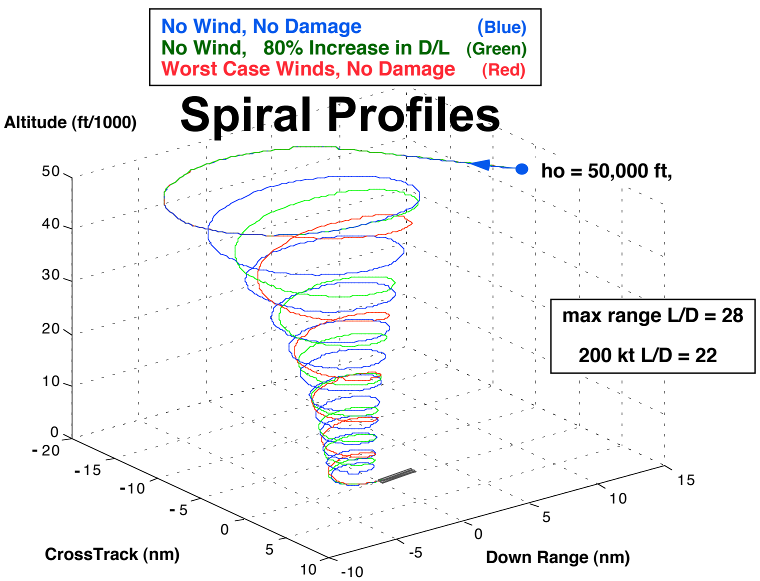
VEHICLE SYSTEMS
Where Innovation Soars

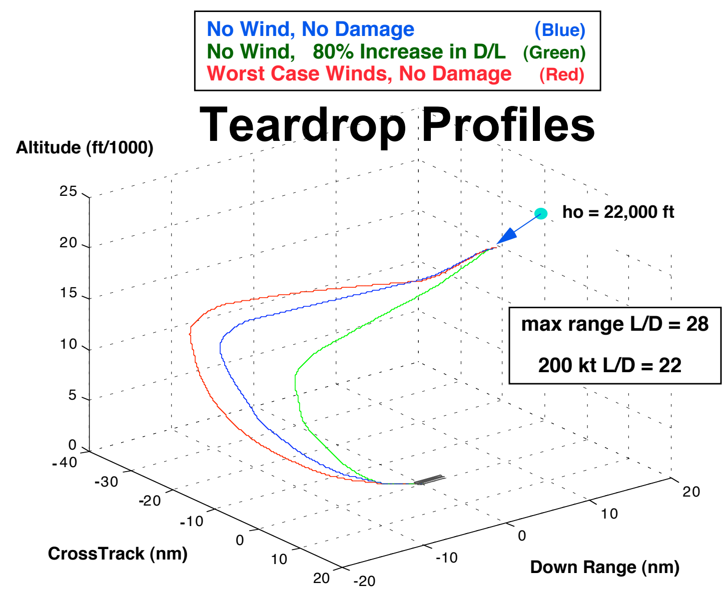
AERONAUTICS research mission directorate

COLA Accomplishments: iFMS

Intelligent Flight Management System (iFMS)

- Generates earth-based trajectories that meet high-level planning objectives and constraints
- Performs energy-management tradeoffs during lateral and vertical flight path construction
- Manages flight-path sequencing, re-planning, and execution



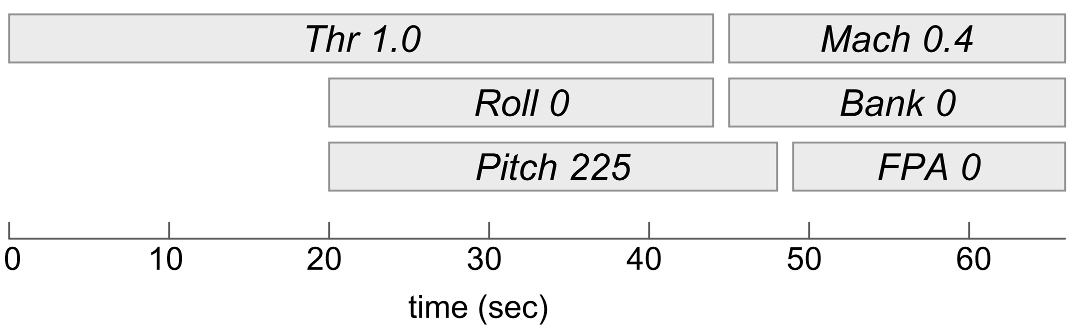


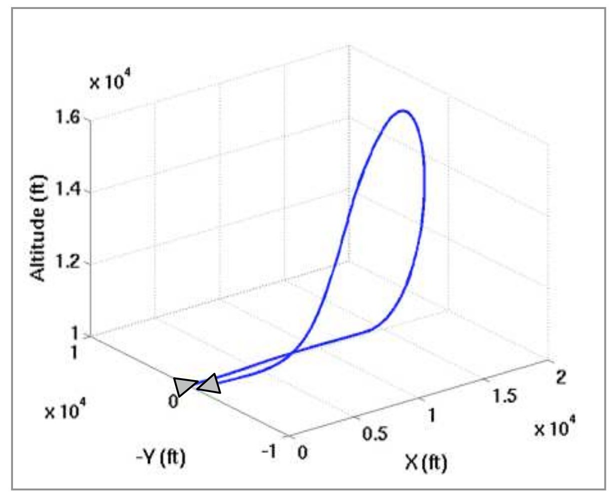
COLA Accomplishments: tactical maneuvering

Tactical Maneuvering

– Generates motion-based trajectories that meet short-term mission payload requirements in respect to vehicle orientation and positioning
– Schedules guidance mode transitions and initiates time critical responses for unexpected conditions

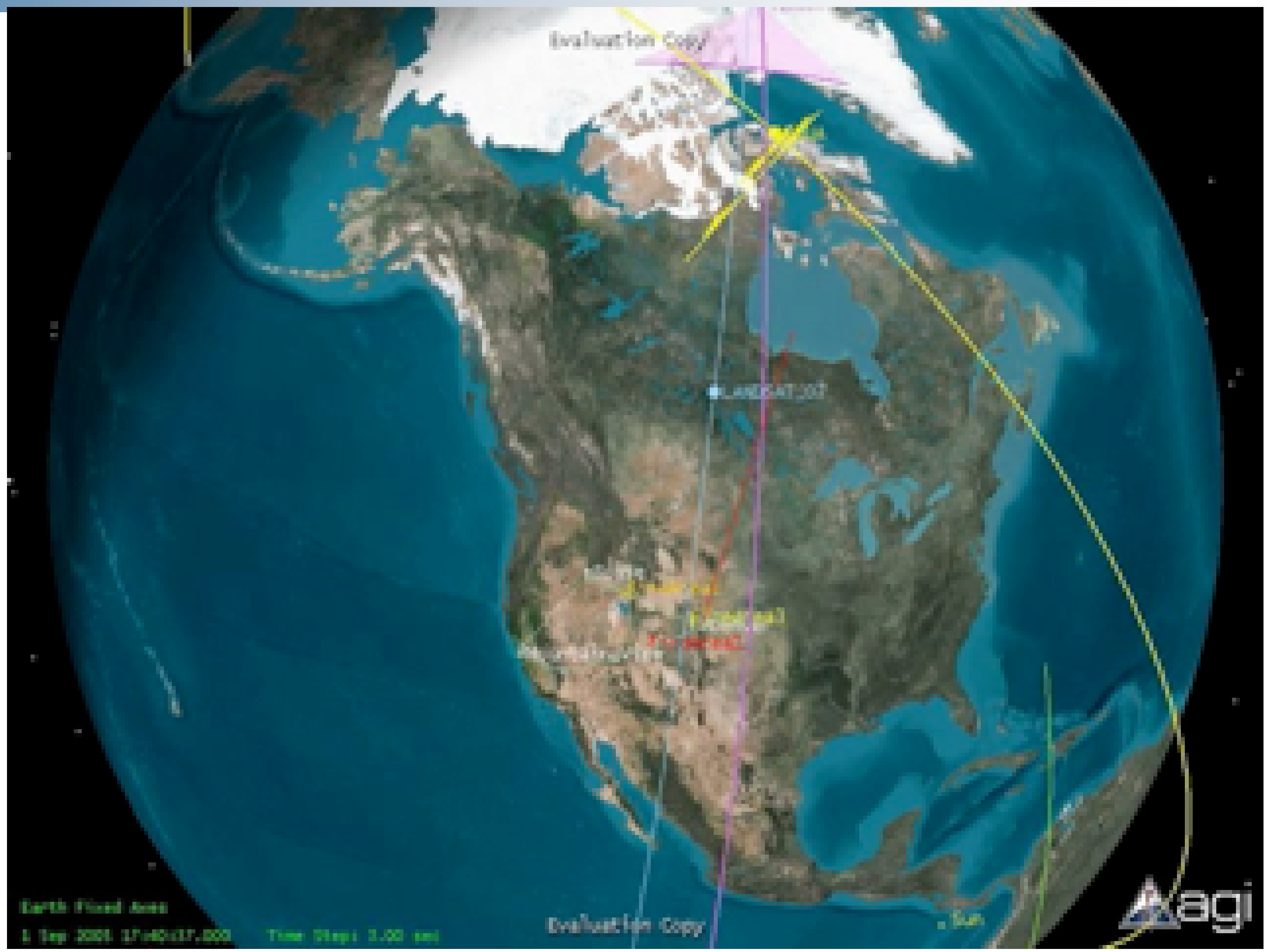
Half-Cuban 8



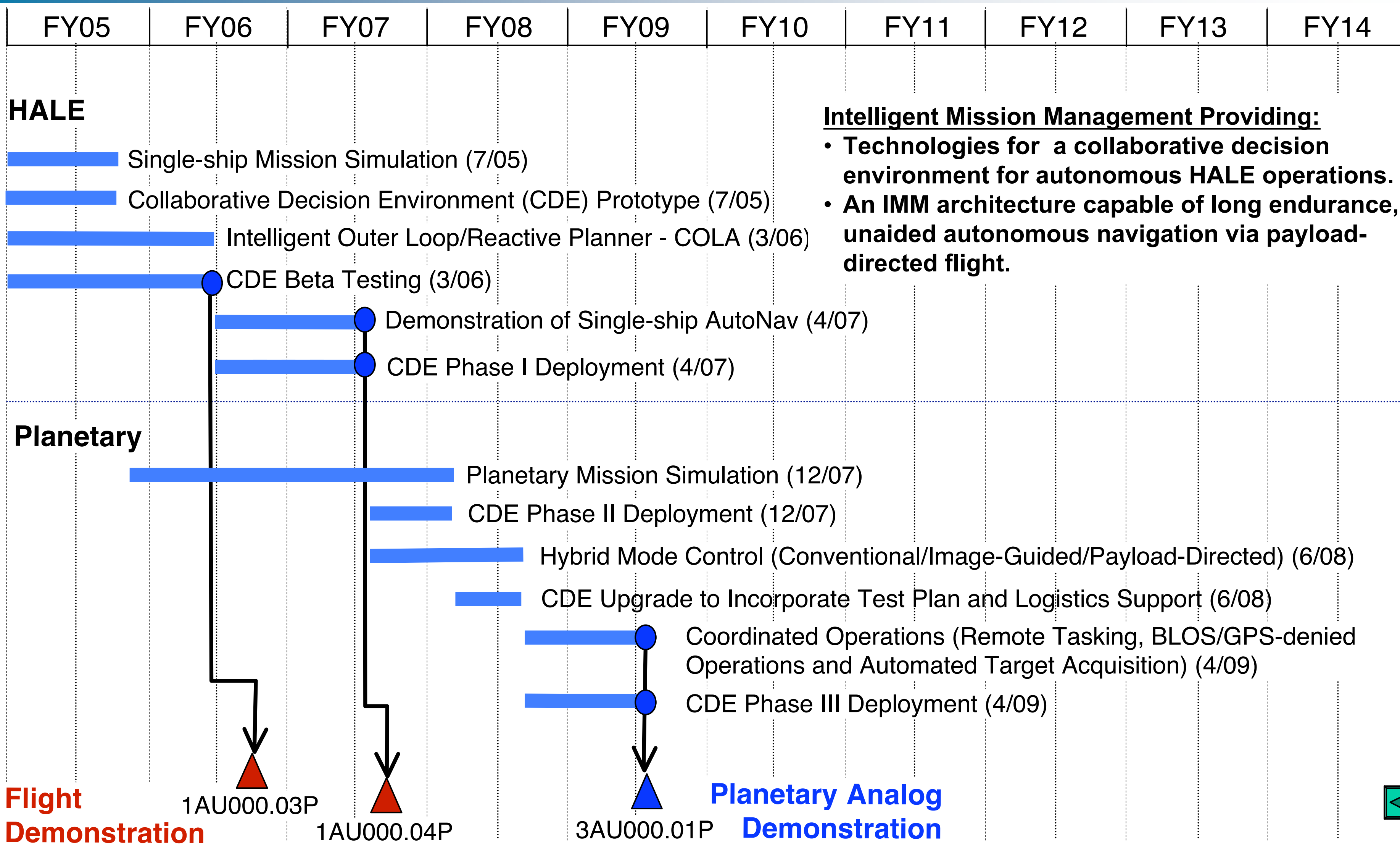


IMM Accomplishments: Coordinated Ops

Animation shows time-synchronous overflight of wildfire by HALE aircraft and MODIS satellite, coordinated by Intelligent Mission Management systems.



Schedule



Intelligent Mission Management Providing:

- **Technologies for a collaborative decision environment for autonomous HALE operations.**
- **An IMM architecture capable of long endurance, unaided autonomous navigation via payload-directed flight.**

Summary

Sector Relevance

Directly addresses goal of Autonomous Mission Operations

- For HALE - addresses autonav, payload-directed tasking, automated contingency management, coordinated ops, mission-level decision support
- For planetary - addresses unaided (GPS-denied) mission management and navigation systems, mission-level decision support, launch and recovery, and autonomous take-off and landing

Invited Technical Session at AIAA Infotech@Aerospace

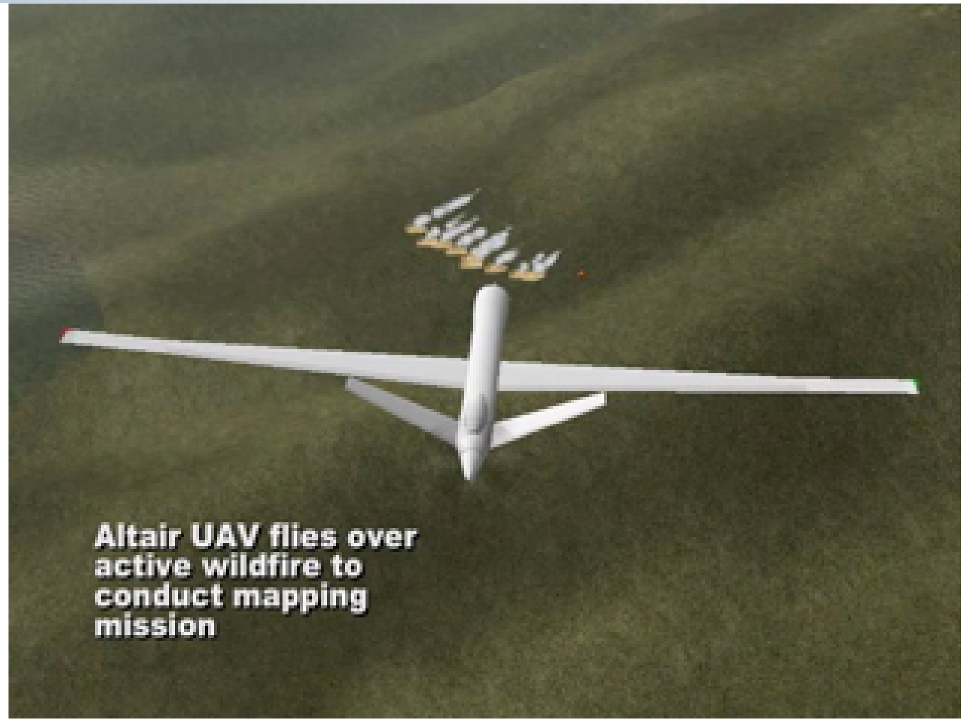
"Intelligent UAV Airborne Science Missions"

"An Architecture for Intelligent Management of Aerial Observation Missions"

"Collaborative Decision Environment for Unmanned Aerial Vehicles"

"Tactical Immunized Maneuvering System for Exploration Air Vehicles"

Transition/Handoff



Transition/Handoff

- Aeronautics Research Mission Directorate
  - Predator-B Testbed and HALE Demonstrator
- Science Mission Directorate
  - Wildfire Research and Applications Partnership
- Exploration Systems Mission Directorate
  - A Plug-and-play Intelligent Avionics Architecture
- Department of Defense
  - U.S. Army Aeroflightdynamics Directorate Autonomous Rotorcraft Project

Risks, Technical Barriers/Challenges

- Sensor-web research, development, and testing
  - Data fusion (assimilation) for land, sea, air, and space measurements
  - Coordinated remote and in-situ tasking
- AutoNav via payload-directed flight for UAV’s (all classes) with multiple payloads
- Remote tasking of deployed assets (e.g. smart dropsondes)
- Reqmts identified for operations in the National Airspace for medium/low altitude and multi-ship

Intelligent Mission Management (IMM)
Joe Totah
Level III Sub-Project Manager

Questions?

Collaborative and Coordinated Systems (CCS)
Francis Enomoto
Level IV Task Lead

Intelligent/Autonomous Architectures (IAA)
Chad Frost
Level IV Task Lead

Matt D'Ortenzio
Matt Fladeland
Sandy Johan
Don Sullivan

Quit Nguyen, QSS
Rajkumar Thirumalanambi, QSS
Pat Finch, CSU-MB
Jian Zheng, CSU-MB
Ted Hildum, SAIC

Mike Freed
John Kaneshige
Kalmanje (Krishna) KrishnaKumar
Craig Pires

John Bull, QSS
Rob Harris, QSS
Miatek Steglinski, NG/Logicon
Stephen Kubik, CSU-SLO

Susan Schoenung, Longitude 120 West Inc.
Steve Wegener, BAER Institute